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NASA CR
NAS-CR 54457

N65-33827
(ACCESSION NUMBER)
49
(PAGES)
(NASA CR OR TMX OR AD NUMBER)
(THRU)
1
(CODE)
17
(CATEGORY)
FACILITY FORM 602

GPO PRICE $
CSFTI PRICE(S) $
Hard copy (HC) 2.00
Microfiche (MF) .50
ff 653 July 65

GENERATION OF LONG TIME CREEP DATA ON REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

EIGHTH QUARTERLY REPORT

Prepared for
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
LEWIS RESEARCH CENTER
UNDER CONTRACT NAS 3-2545

TRW EQUIPMENT LABORATORIES
CLEVELAND, OHIO

NAS-CR 54457

EIGHTH QUARTERLY REPORT

FOR

MARCH 26, 1965 to JUNE 26, 1965

GENERATION OF LONG TIME CREEP DATA OF REFRACTORY ALLOYS AT ELEVATED TEMPERATURES

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Prepared for:

National Aeronautics and Space Administration
Contract No. NAS 3-2545

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July 7, 1965

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FOREWORD

The work described herein is being performed by TRW Inc. under the sponsorship of the National Aeronautics and Space Administration under Contract NAS 3-2545. The purpose of this study is to obtain design creep data on refractory metal alloys for use in space power systems.

The program is administered for TRW Inc. by E. A. Steigerwald, Program Manager. J. C. Sawyer is the Principal Investigator. C. H. Philleo, C. R. Honeycutt and R. R. Ebert contributed to the program.

ABSTRACT

33827

Creep data obtained under ultra high vacuum conditions are presented for molybdenum-base alloys TZC and TZM, columbium-base alloy Cb132M, and arc-melted tungsten, arc-melted tungsten-25% rhenium, and Sylvania A. The results indicate that in the 1800°F (982°C) to 2200°F (1204°C) temperature range the TZC alloy possesses the greatest degree of creep resistance.

author

TABLE OF CONTENTS

I. INTRODUCTION

Space electric power systems depend upon the use of refractory metals in a variety of component areas. A critical property parameter in the design of these systems is the long-time creep strength at very low partial pressures of oxygen and nitrogen. Contamination of refractory metal alloys can occur under conditions of 10^{-6} Torr and vacuums better than 10^{-8} Torr must be used to obtain creep measurements which can be employed for design of space components. The purpose of this program is to generate long-time creep data on selected refractory alloys which have potential use in advanced power systems. Emphasis has been placed on testing sheet alloys which can be employed for cladding or tubing applications and on forgeable high strength turbine alloys.

The design of the test units capable of operating at vacuums less than 10^{-8} Torr and temperatures up to 3200°F, has been previously described. Creep test data have also been presented for tungsten and tungsten-25% rhenium sheet, molybdenum base alloys TZC and TZM and columbium base alloys AS-30 and FS-85. Additional results for these alloys along with data obtained on columbium alloy Cb132M and the tungsten-base Sylvania A alloy are described in this report.

II. MATERIALS AND PROCEDURE

The materials currently included in the test program along with their compositions are presented in Tables 1 and 2. The tantalum base alloy T-111 has been recently added to the program due to its potential applicability as a tubing material. A TZM alloy obtained by Air Research Corporation* and received from NASA has also been included to provide a measure of the reproducibility in creep properties between two heats of the same material with different carbon contents.

A detailed description of the test specimen geometry, the test procedure, and the material processing history for TZM, TZC (Heat M80), AS-30, W, W-25Re, and Sylvania A were presented in the sixth and seventh Quarterly Reports. The processing history for Cb132M is given in Appendix I. The evaluation method involves testing the turbine or tubing alloys at

* R. L. Salley and E. A. Kovacevich, "Materials Investigation, Snap 50/Spur Program Mechanical Properties of TZM", Tech. Rep. AFAPL-TR-65 (March 23, 1965).

TABLE 1

Summary of Material Variables Being Evaluated in Creep Program

Material	Form	Test Temperature	Test Condition
Tungsten	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 2 hours, 3200°F (1760°C)
Tungsten-25% Rhenium	Arc-Melted 0.030" Sheet	3200°F (1760°C)	Recrystallized 2 hours, 3200°F (1760°C)
Sylvania A	Powder Metallurgy 0.030" Sheet	3200°F (1760°C)	Recrystallized 2 hours, 3200°F (1760°C)
Tungsten	Vapor-deposited 1/8" Dia. Bars	3200°F (1760°C)	As-received
AS-30	3/4" Plate	2000-2200°F (1093-1204°C)	As-received, stress-relieved condition, (Rc 29)
Cb132M	3/4" Plate	2056-2256°F (1124-1235°C)	Annealed 1 hour, 3092 °F (1700°C)
TZM (Climax Heat 7502)	"Pancake" Forging	2000°F (1093°C)	(Cond. 1) As-received, stress-relieved condition (Rc 32) (Cond. 2) Annealed 1 hour, 2850°F (1566°C)
TZM (Air Research)	Forging	1600-1856°F (871-1013°C)	As-received, stress-relieved, 2300°F (1260°C) 1 Hour
TZC	3/4" Plate	1856-2200°F (1013-1204°C)	Recrystallized 1 hour, 3092°F (1700°C)
T-222*	0.030" Sheet	1800-2200°F (982-1204°C)	Annealed 3000°F (1649°C) 1 Hour
T-111	0.030" Sheet	1800,2000,2200°F (982,1093,1204°C)	As-received

* Originally scheduled to be tested as ST-222 plate material, program plan revised to include material as T-222 grade applicable for tubing.

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TABLE 2

Chemical Composition of Alloys Being Evaluated in Creep Program (Weight %)

Material	W	Re	Cb	Mo	Ta	Hf	C	N_2	Ti	Zr	Ni	ppm O_2	ppm H_2
Tungsten	Bal.												
Tungsten-25% Rhenium	Bal.	24.9											
Sylvania A	Bal.					0.52	.030						
AS-30			Bal.				.064	.015	.03	.940	.02	145	3
Cb132M	15.0		Bal.	5.07	19.8		.150			2.170		4	4
TZM (Climax Heat 7502)				Bal.			.013	.001	.47	.091			
TZM (Air Research)			Bal.				.03	To be analyzed					
TZC			Bal.				.080	.002	1.02	.130			
ST-222 (T-222)	10.4				Bal.	2.47	.0086						
T-111	8.0				Bal.	1.85	.004	.005				140	4

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temperatures between 1600 and 2250°F (871 and 1235°C) until a 1% total elongation is attained. The cladding materials are tested at 3200°F (1760°C) for a total extension up to 5%. In all cases the test environment (after approximately the first 100 hours of test) is less than 10^{-8} Torr and the applied stress levels are selected with the goal of obtaining creep data over total test times between 1000 and 10,000 hours.

III. EXPERIMENTAL RESULTS

A. Molybdenum-Base Alloys (TZC and TZM)

A detailed presentation of the creep data for all the tests is given in Appendix II. The creep curves for tests being conducted on TZC at temperatures of 1856, 2000, 2056, and 2200°F (1013, 1093, 1124, and 1204°C) are presented in Figures 1 and 2. The tendency for the creep curves to exhibit discontinuties was more prevalent at the higher test temperatures. Metallographic examination is currently being conducted in an attempt to relate the discontinuties in the creep curves to precipitation which is occurring during the test.

The hardness of the as-received TZC plate (Heat M-80) from the surface to the center showed little variation (DPH 288 to 285). A representative structure of the as-received material at the center of the plate is shown in Figure 3. The microstructure of the TZC plate after annealing at 3092°F(1700°C) for one hour is presented in Figure 4A; while the structure of a specimen after exposure to a 2000°F (1093°C) test condition for approximately 1200 hours is shown in Figure 4B. The annealing treatment produced a material with a 0.2% yield strength of 69.5 ksi (47.2×10^7 N/m^2), a tensile strength of 68.6 ksi (47.4×10^7 N/m^2) and a zero reduction in area at room temperature when measured transverse to the rolling direction. The annealing treatment did not result in a completely recrystallized structure, however, it did produce a noticeable reduction in hardness (DPH 288 to DPH 235). After testing for approximately 1200 hours at 2000°F (1093°C) the hardness of the TZC increased to DPH 350 indicating that significant precipitation hardening had occurred during testing.

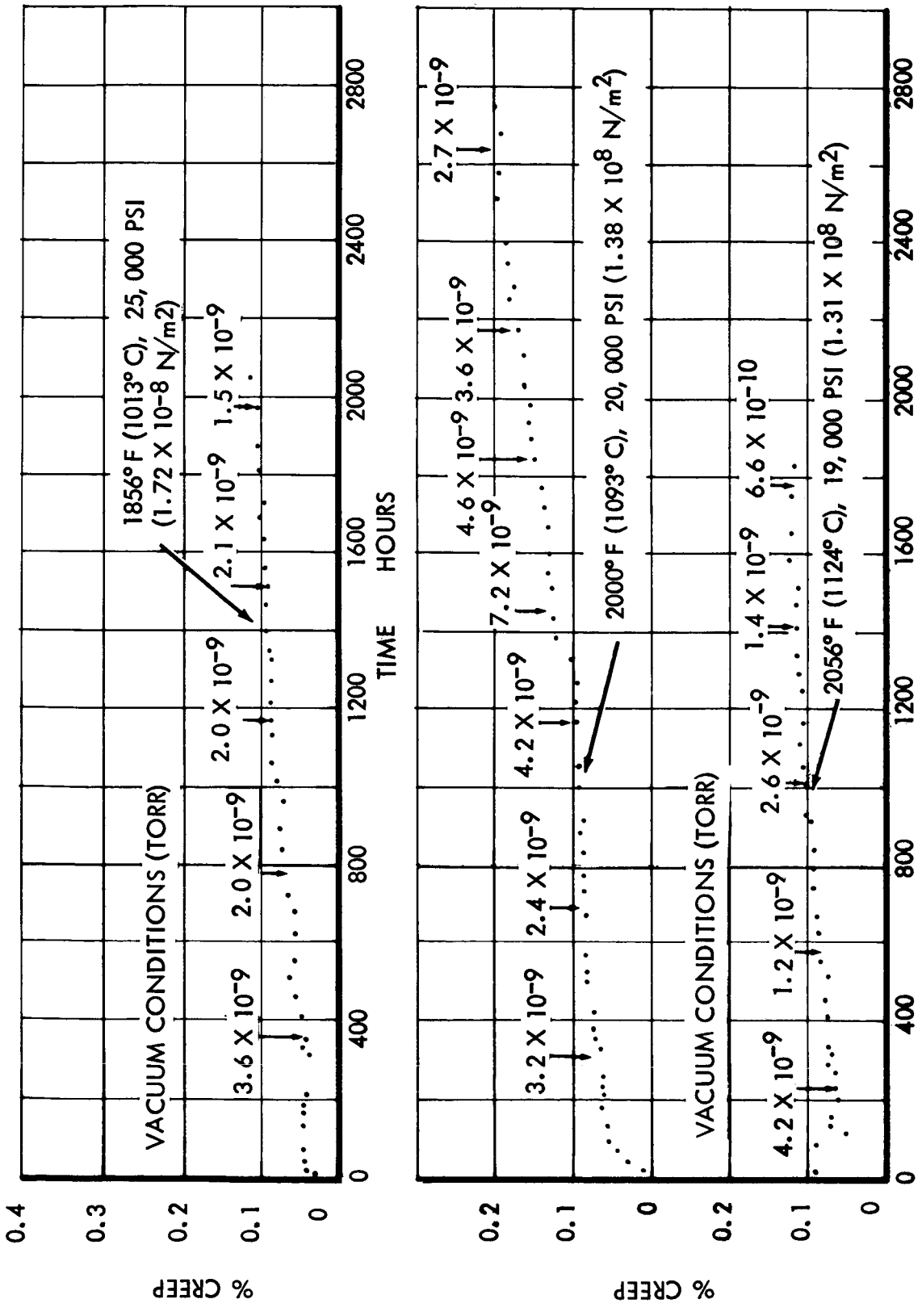

FIGURE 1. CREEP DATA FOR TZC PLATE (HEAT M-80) RECRYSTALLIZED AT 3092° F (1700° C), TESTED IN VACUUM ENVIRONMENT

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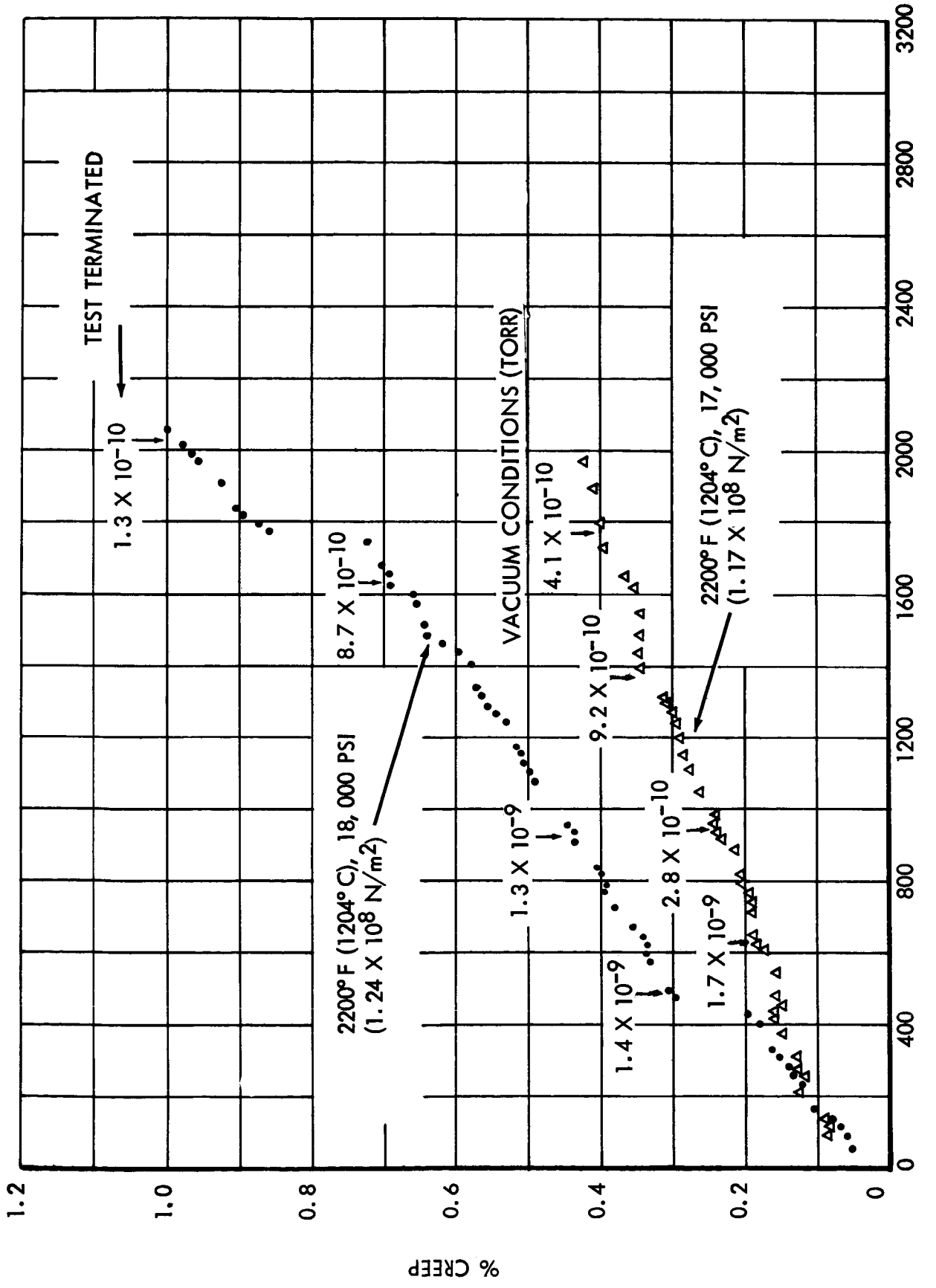

FIGURE 2. CREEP DATA FOR TZC PLATE (HEAT M-80) RECRYSTALLIZED AT 3092°F (1700°C), TESTED IN VACUUM ENVIRONMENT

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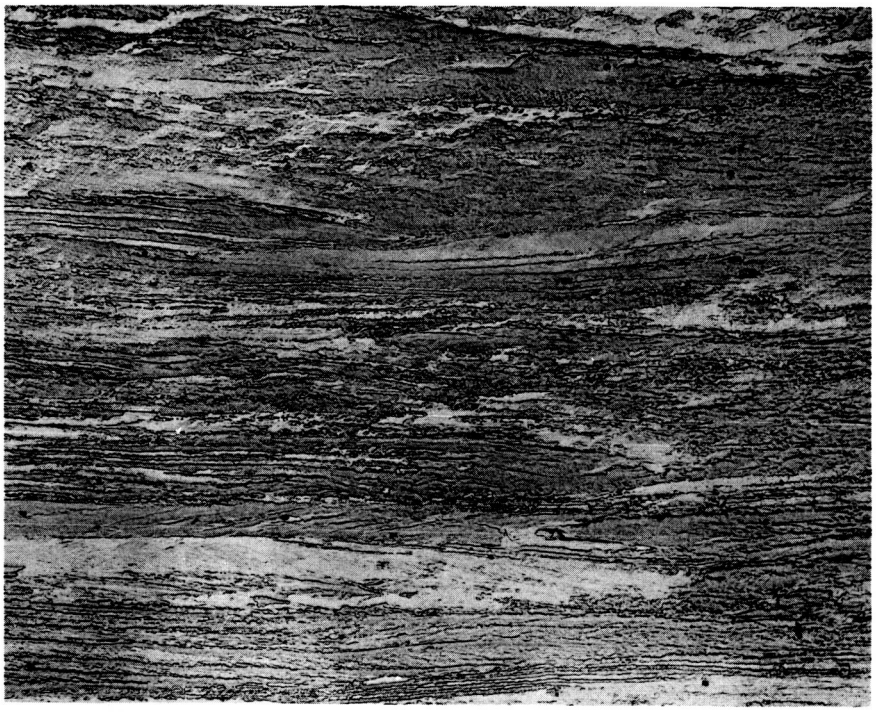

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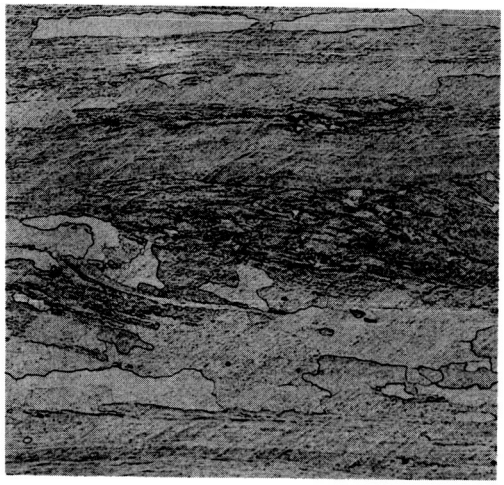
FIGURE 3. STRUCTURE OF TZC ALLOY IN AS-RECEIVED CONDITION, ETCHANT: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O



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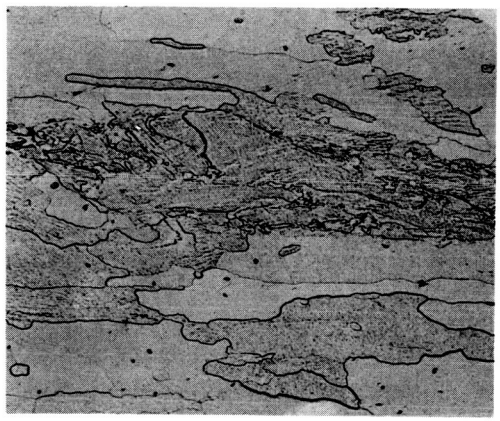
A. STRUCTURE AFTER ANNEALING AT 1700° C FOR 1 HOUR
HARDNESS DPH 288



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B. STRUCTURE AFTER ANNEALING AT 1700° C FOR 1 HOUR AND TESTING FOR 1196 HOURS AT 1094° C (2000° F) HARDNESS DPH 350

FIGURE 4. STRUCTURE OF TZC ALLOY (HEAT M-80) AFTER ANNEALING AND AFTER TESTING. ETCHANT: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2)

The creep behavior for TZM (Heat 7502) in both the as-received (stress-relieved) and annealed condition is presented in Figure 5. The as-received material exhibited a relatively normal creep curve while the annealed condition produced a very rapid increase in the total elongation at approximately 350 hours. The sharp increase was followed by a low creep rate and time intervals where actual specimen contraction was observed. Although no definite explanation is apparent for this behavior it is characteristic of conditions where a phase change and creep are occurring simultaneously.*

The Air Research TZM alloy received from NASA is currently under tests at 1856°F (1013°C) and 24,000 psi (1.65×10^8 N/m^2). After 496 hours a total extension of 0.02% has been obtained.

A comparison of the creep properties of the TZC and TZM material is presented in Figure 6 on a Larson-Miller plot using a constant of 15. The stress to produce 0.2% total extension in TZC was approximately a linear function of the Larson-Miller parameter over a relatively large range of times and temperatures. The data obtained for the stress-relieved TZM (0.013%C) (Heat 7502) indicated that this material had creep resistance which was significantly below the TZC alloy. The plot for the 0.5% creep level indicated that a slight deviation from linearity was present at the lower values of the Larson-Miller parameter.

B. Columbium-Base Alloy (Cb132M)

The creep properties of the Cb132M alloy were evaluated after annealing the material for one hour at 3092°F (1700°C). This treatment produced a partially recrystallized structure (see Figure 7) having the room temperature properties listed in Table 3.

TABLE 3

Room Temperature Properties of Cb132M after Annealing at 3092°F (1700°C) for One Hour in Vacuum (10^{-6} Torr)

0.2% Yield Strength	109.8 ksi (7.56×10^8 N/m^2)
Tensile Strength	121.2 ksi (8.36×10^8 N/m^2)
Elongation (2")	4.2%
Reduction in Area	4.7%
Strain Rate	0.005 in/in/min.

* R. W. Fountain and M. Korchynsky, "The Phenonemon of 'Negative Creep' in Alloys", Trans. ASM, 51, 108, (1959).

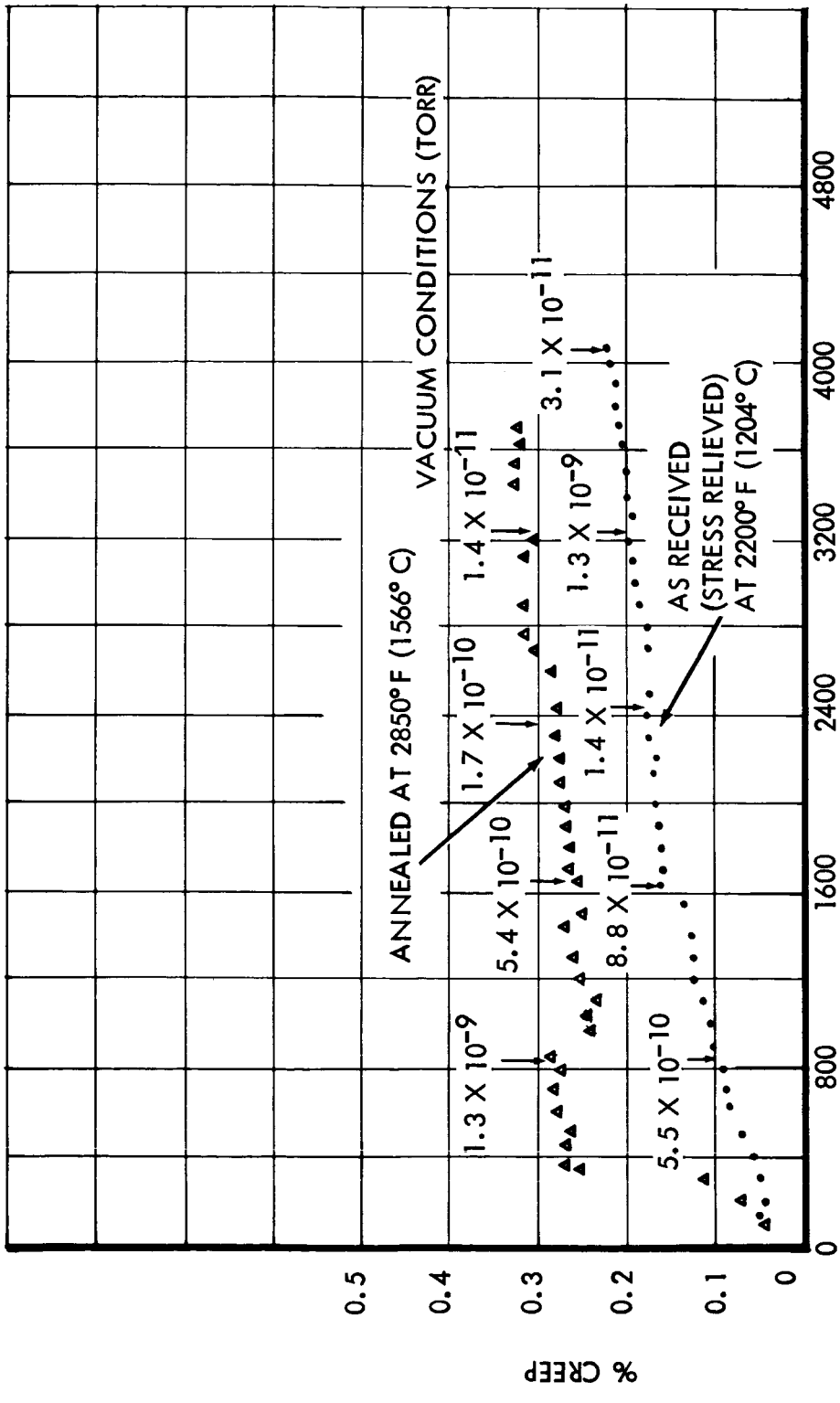

FIGURE 5. CREEP DATA FOR TZM (HEAT 7502) AT 2000°F (1093° C), 10,000 PSI (6.9×10^8 N/m^2) TESTED IN VACUUM ENVIRONMENT

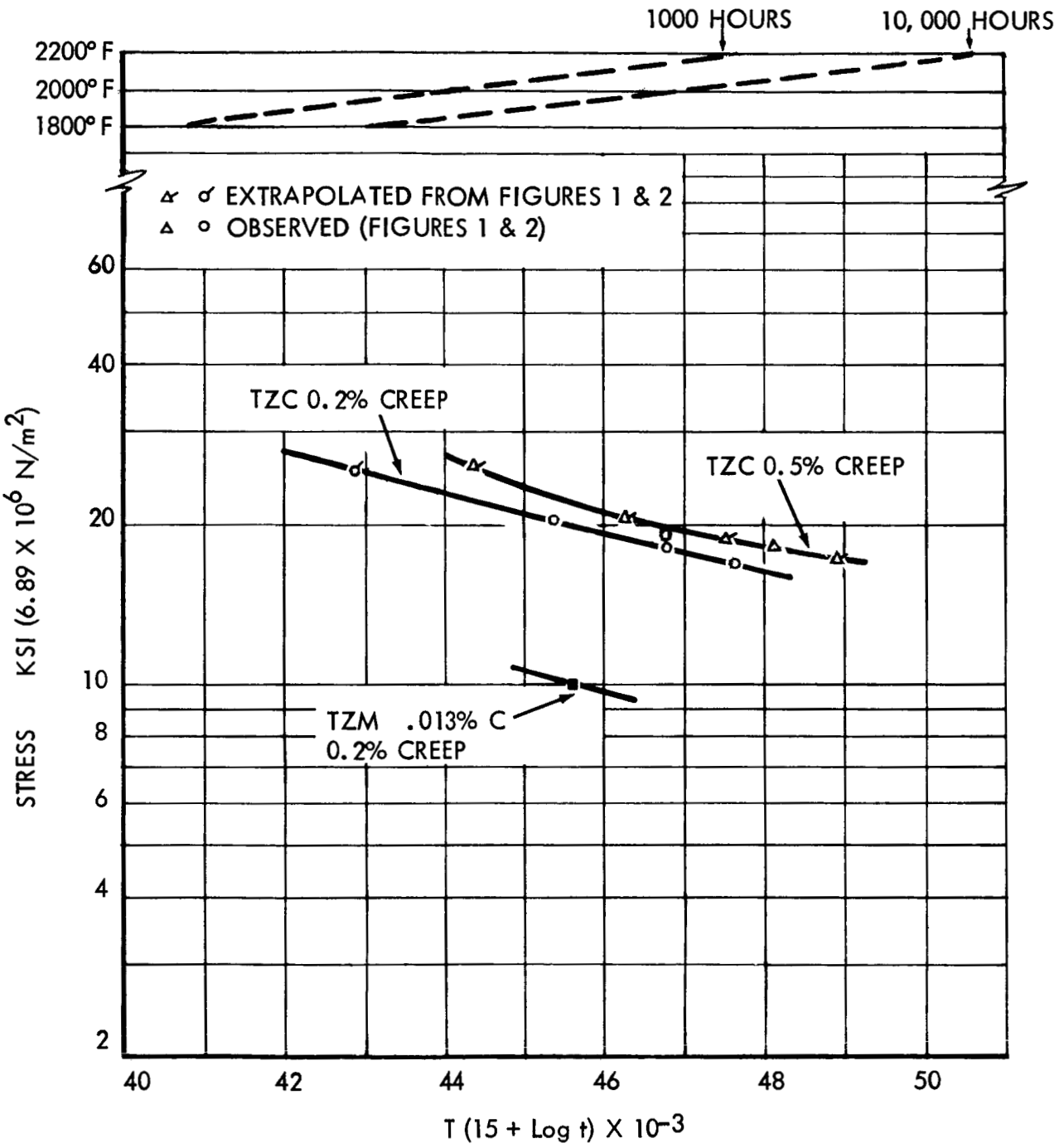

FIGURE 6. LARSON-MILLER PLOT OF CREEP DATA FOR TZC (HEAT M-80) AND TZM (HEAT 7502)

9730

100X

FIGURE 7. MICROSTRUCTURE OF Cb 132M ALLOY AFTER ANNEALING AT 3092° F (1700° C) FOR ONE HOUR, ETCHANT: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O

Creep test data obtained at 2056°F (1124°C) on Cb132M are summarized in Figure 8. A comparison of the two columbium base alloys, Cb132M and AS-30, is presented in terms of the Larson-Miller parameter in Figure 9. At the stresses evaluated, the Cb132M alloy had creep resistance superior to AS-30 but inferior to the molybdenum alloys. An additional test is being conducted at 2200°F (1204°C), 8,000 psi ($5.5 \times 10^7 N/m^2$) to examine the behavior of Cb132M at higher values of the Larson-Miller parameter.

C. Tungsten-Base Materials

The results of creep tests conducted on arc-melted tungsten and tungsten-25% rhenium alloys were summarized in the last Quarterly Progress Report for total extensions of 1%. Results obtained during this report period included additional creep data for tungsten, tungsten-25% rhenium, and Sylvania A. The tungsten and tungsten-25% rhenium creep curves are shown in Figure 10. There was a tendency for the tungsten tests at 1000 psi ($6.8 \times 10^6 N/m^2$) to exhibit a continuously decreasing creep rate. As a result, the extrapolations of short-time data would tend to predict creep extensions which were significantly greater than the true values. At the relatively low stress of 1000 psi ($6.8 \times 10^6 N/m^2$) the unalloyed tungsten showed a total extension at 3200°F (1760°C) of 2.47% after approximately 3000 hours, while an extrapolation of the data after 1000 hours would have resulted in a prediction which was 50% higher.

The Sylvania A material possessed a large number of imperfections in the surface of the sheet and examination by radiography was required to insure that these defects were not located in the specimen gauge section. Two tests were initiated with this material, however, specimen failure occurred in both cases outside the gauge section at approximately the position where the specimen passed through the furnace heat shields. The failure appeared to be initiated by a brittle crack which propagated from one side. The resultant bending stresses and reduction in cross-sectional area were sufficient to cause specimen failure. The specimens were machined by electric discharge methods and examination prior to testing indicated that the cracks were not induced by the machining operation. At a stress of 5000 psi ($3.45 \times 10^8 N/m^2$) a total extension of 0.25% was obtained in 18 hours on the first specimen and a creep of 0.20% in 26 hours on the second specimen. The microstructure of the Sylvania A material after testing is shown in Figure 11.

IV. FUTURE WORK

During the next report period additional tests will be initiated on the Air Research TZM material obtained from NASA. The T-222 material has been received and will also be tested along with the vapor-deposited tungsten.

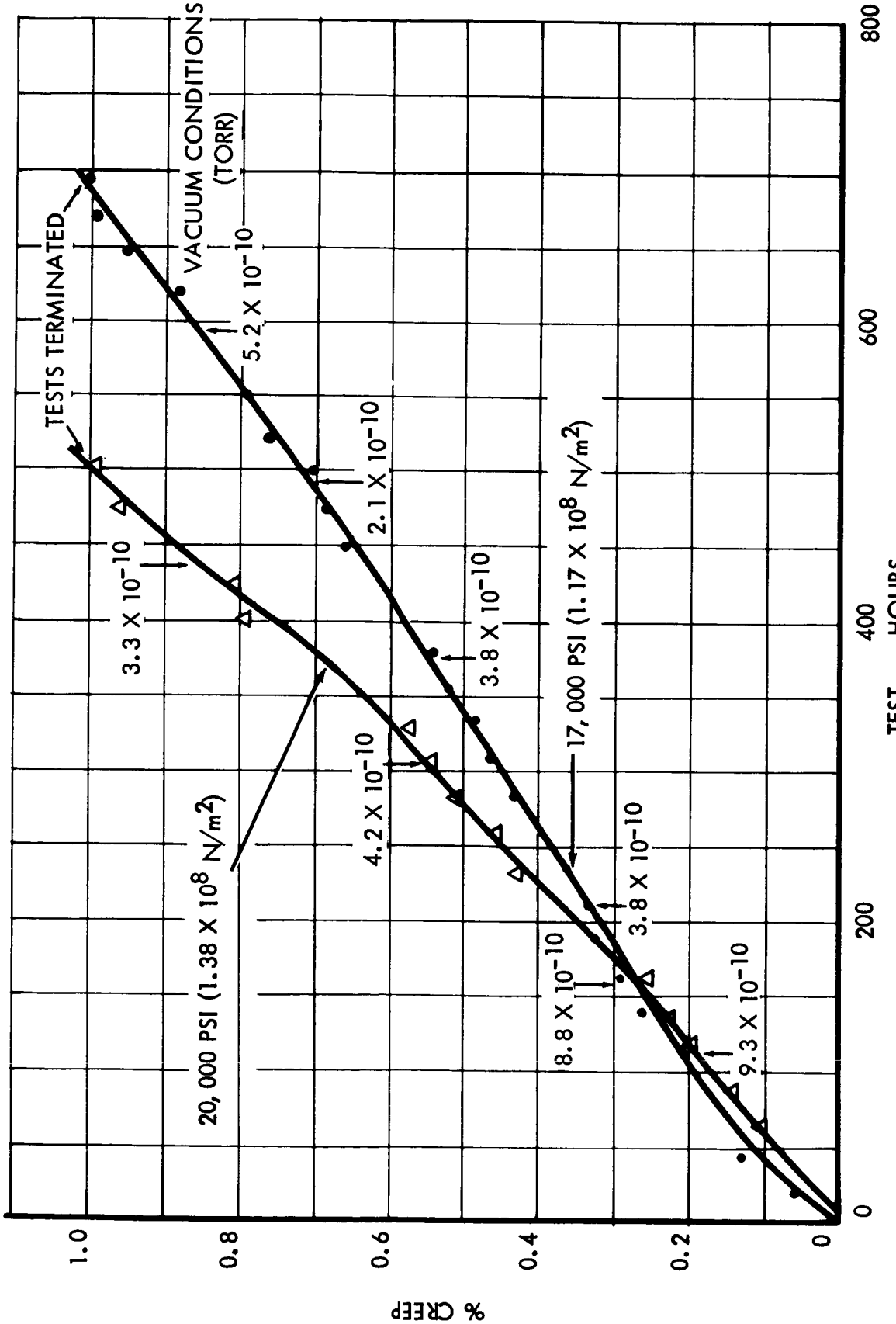

FIGURE 8. CREEP DATA FOR Cb 132 M ANNEALED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2056°F (1124°C) IN VACUUM ENVIRONMENT

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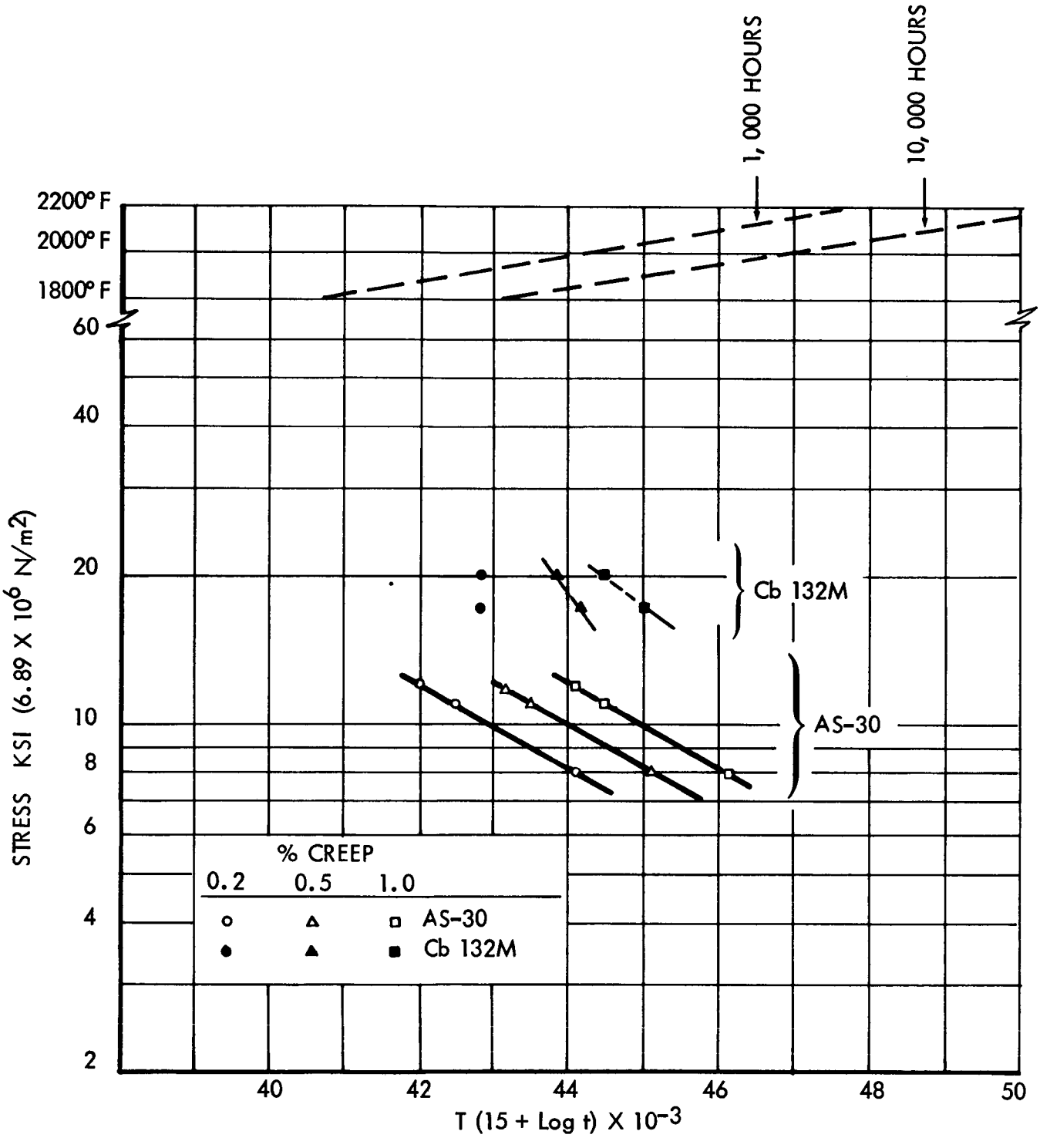

FIGURE 9. LARSON MILLER PLOT OF CREEP DATA FOR AS-30 AND Cb 132M ALLOYS

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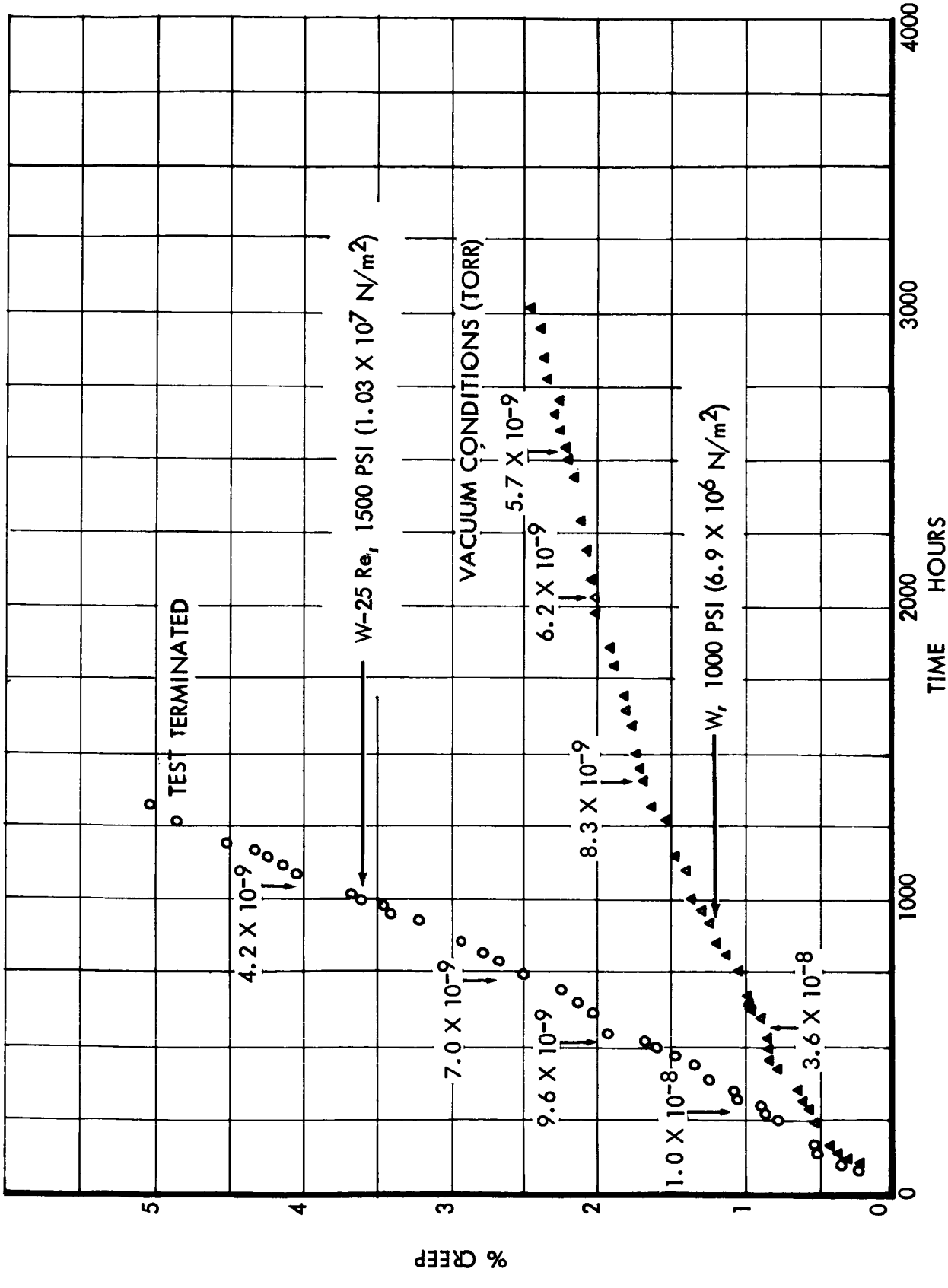

FIGURE 10. CREEP DATA FOR ARC CAST TUNGSTEN AND TUNGSTEN - 25% RHENIUM, RECRYSTALLIZED AT 3200°F (1760°C), 1 HOUR, TESTED AT 3200°F (1760°C) IN VACUUM ENVIRONMENT

9731

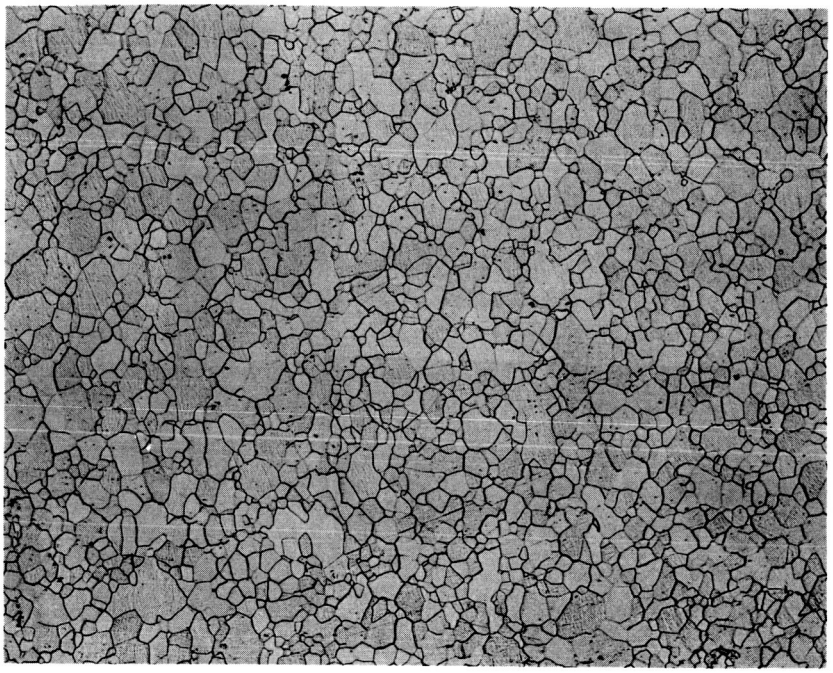

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FIGURE 11, STRUCTURE OF SYLVANIA A ALLOY AFTER RECRYSTALLIZATION AT 3200° F (1760° C) FOR 1 HOUR, AND TESTING AT 3200° F (1760° C) FOR 26 HOURS, HARDNESS DPH 438, ETCHANT: 15% HF, 15% H_2SO_4, 8% HNO_3, 62% H_2O

APPENDIX I

Processing History of Cb132M

Universal Cyclops Heat No. KC 1454

1. Electron-beam melted stock with carbon added by Universal Cyclops, electrode diameter 2-1/2" mold size 3-7/8".

2. Vacuum arc melted, then canned in Mo-0.5Ti.

3. Extruded at 3130°F to 1-1/2" diameter.

4. Cross-rolled from 2400°F in three passes yielding reductions of 20, 10, and 10%. Plate reheated between each pass. Final thickness 3/4".

5. Jacket removed, shipped in as-rolled structure.

APPENDIX II

Creep Test Data

TABLE A-1

Creep Test Data, TZC Plate, Recrystallized at 3092°F (1700°C)

For 1 Hour, Tested At 1856°F (1013°C), 25,000 psi ($1.72 \times 10^8 N/m^2$)

Time (Minutes)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
1	-.00005	-.0025	4×10^{-9}
2	-0-	-0-	
3	-.00005	-.0025	
4	.00005	.0025	
5	.00005	.0025	
6	.00010	.0005	
7	.00005	.0025	
8	-0-	-0-	
9	-0-	-0-	
10	.00005	.0025	
15	-.00005	-.0025	
20	.00015	.0075	
25	.00015	.0075	
30	.00025	.012	
60	.00065	.032	

TABLE A-I (Cont'd.)

Creep Test Data, TZC Plate, Recrystallized at 3092°F (1700°C)
For 1 Hour, Tested At 1856°F(1013°C), 25,000 psi (1.72 X 10^8 N/m^2)

Time (Hours)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
1	.00065	.032	1.5×10^{-8}
19.3	.00085	.042	1.4×10^{-8}
42.1	.00095	.047	1.3×10^{-8}
68.2	.00095	.047	1.1×10^{-8}
138.4	.0009	.045	5.8×10^{-9}
162.8	.00085	.042	6.6×10^{-9}
186.0	.00085	.042	6.8×10^{-9}
210.3	.0008	.040	5.8×10^{-9}
306.2	.00075	.037	5.2×10^{-9}
330.2	.0009	.045	4.4×10^{-9}
354.2	.00085	.042	3.4×10^{-9}
402.4	.00095	.047	3.6×10^{-9}
460.7	.00105	.052	2.5×10^{-9}
508.5	.00125	.062	3.4×10^{-9}
556.8	.00105	.052	3.2×10^{-9}
628.9	.00105	.052	3.0×10^{-9}
681.7	.00115	.057	--
725.6	.00125	.062	3.1×10^{-9}
796.4	.0013	.065	2.0×10^{-9}
844.8	.00145	.072	2.2×10^{-9}
892.4	.00145	.072	1.6×10^{-9}
964.6	.0014	.070	2.8×10^{-9}
1012.6	.00155	.077	2.7×10^{-9}
1060.7	.0017	.085	2.6×10^{-9}
1132.3	.00165	.082	2.4×10^{-9}
1186.9	.00165	.082	2.0×10^{-9}
1228.6	.0017	.085	1.8×10^{-9}
1277.8	.0017	.085	2.2×10^{-9}
1324.4	.00165	.082	2.3×10^{-9}
1349.2	.00175	.087	1.4×10^{-9}
1396.3	.00185	.092	1.8×10^{-9}
1468.3	.00185	.092	2.5×10^{-9}
1516.4	.0018	.090	2.6×10^{-9}
1564.4	.00185	.092	3.1×10^{-9}
1636.4	.00195	.097	2.5×10^{-9}
1689.1	.00205	.102	2.2×10^{-9}
1732.4	.00195	.097	2.8×10^{-9}
1804.3	.0020	.100	2.0×10^{-9}
1876.7	.00215	.107	2.0×10^{-9}
1972.6	.00210	.105	2.3×10^{-9}
2044.4	.00225	.112	9.6×10^{-9}

Test in Progress

TABLE A-II

Creep Test Data, TZC Plate, Recrystallized at 3092°F (1700°C)

For 1 Hour, Tested At 2056°F (1124°C), 25,000 psi ($1.72 \times 10^8 N/m^2$)

Time (Minutes)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
1	.00010	.005	7.0×10^{-8}
2	.00020	.010	
3	.00030	.015	
4	.00050	.025	
5	.00055	.027	
6	.00065	.032	
7	.00085	.043	
8	.00095	.047	
9	.00105	.052	
10	.00120	.060	
12	.00130	.065	
13	.00140	.070	
14	.00150	.075	
15	.00160	.080	6.9×10^{-8}
20	.00165	.082	
25	.00170	.085	
30	.00170	.085	6.9×10^{-8}
40	.00175	.087	
45	.00175	.087	
60	.00180	.090	6.8×10^{-8}
90	.00180	.090	6.7×10^{-8}

TABLE A-II

Creep Test Data, TZC Plate, Recrystallized at 3092°F (1700°C) for 1 Hour, Tested at 2056°F (1124°C), 19,000 psi (1.3. X 10^{-8} N/m^2)

Time (Hours)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
15.5	.0018	.090	3.5×10^{-8}
87.1	.0018	.090	1.4×10^{-8}
111.2	.0010	.050	9.8×10^{-9}
133.4	.0014	.070	7.0×10^{-9}
159.0	.00135	.067	3.0×10^{-9}
181.6	.0013	.065	--
239.9	.00135	.067	4.2×10^{-9}
263.7	.0013	.065	5.1×10^{-9}
287.7	.0015	.075	4.5×10^{-9}
309.9	.0014	.070	3.8×10^{-9}
334.3	.0015	.075	3.2×10^{-9}
406.5	.00145	.072	3.5×10^{-9}
459.3	.00155	.077	--
503.2	.0015	.075	2.2×10^{-9}
573.9	.00175	.087	1.2×10^{-9}
622.5	.00175	.087	1.1×10^{-9}
669.9	.0018	.090	3.8×10^{-9}
742.3	.00185	.092	2.8×10^{-9}
790.2	.0019	.095	2.8×10^{-9}
838.3	.00185	.092	1.8×10^{-9}
909.9	.00195	.097	3.2×10^{-9}
964.8	.00205	.102	2.6×10^{-9}
1006.2	.00210	.105	2.6×10^{-9}
1055.3	.00215	.107	2.7×10^{-9}
1102.0	.0022	.110	2.9×10^{-9}
1126.8	.0022	.110	1.7×10^{-9}
1173.9	.0022	.110	1.0×10^{-9}
12.45.9	.00215	.107	4.2×10^{-9}
1294.0	.00225	.112	2.1×10^{-9}
1342.0	.00235	.117	2.1×10^{-10}
1414.1	.00235	.117	1.4×10^{-9}
1466.7	.00235	.117	2.5×10^{-9}
1509.9	.00225	.112	2.0×10^{-9}
1581.8	.00245	.122	7.5×10^{-10}
1654.2	.00245	.122	1.2×10^{-9}
1750.2	.0024	.120	1.3×10^{-9}
1822.1	.00235	.117	7.0×10^{-10}
Test in Progress			

TABLE A-III

Creep Test Data, TZC Plate, Recrystallized at 3092°F(1700°C)

For 1 Hour, Tested at 2000°F (1093°C), 20,000 psi (1.38×10^{-8} N/m^2)

Time (Minutes)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
1	-0-	-0-	1.2×10^{-9}
2	-.00020	-.010	
3	-.00040	-.020	
4	-.00030	-.015	
5	-.00030	-.015	
10	-.00005	-.002	
15	.00005	.002	
20	.00005	.002	
25	.00010	.005	
30	.00010	.005	
60	.00005	.002	
90	-.00005	-.002	

TABLE A-III

Creep Test Data, TZC Plate, Recrystallized at 3092°F(1700°C) For 1 Hour, Tested at 2000°F (1093°C), 20,000 psi (1.38×10^{-8} N/m^2)

Time (Hours)	Length Change Δ L (in.) 2" G.L.	Creep %	Pressure Torr
17.2	.0004	.020	2.6×10^{-9}
41.3	.0006	.030	2.2×10^{-9}
65.2	.0008	.040	2.2×10^{-9}
89.2	.0011	.055	2.0×10^{-9}
161.3	.00105	.052	1.3×10^{-9}
209.1	.0012	.060	1.7×10^{-9}
233.2	.0012	.060	1.4×10^{-9}
257.3	.00125	.062	1.3×10^{-9}
329.2	.00135	.067	2.0×10^{-9}
355.9	.0014	.070	3.2×10^{-9}
377.0	.0014	.070	3.4×10^{-9}
401.1	.0014	.070	2.4×10^{-9}
425.0	.00145	.072	1.5×10^{-9}
497.2	.00165	.082	1.9×10^{-9}
521.4	.00165	.082	3.1×10^{-9}
569.2	.00165	.082	4.5×10^{-9}
665.2	.0016	.080	5.0×10^{-9}
713.3	.00155	.077	4.6×10^{-9}
762.8	.00165	.082	--
833.4	.00170	.085	1.5×10^{-8}
881.0	.0018	.090	6.1×10^{-9}
905.2	.0017	.085	5.8×10^{-9}
1001.1	.0018	.090	3.9×10^{-9}
1049.2	.0018	.090	6.4×10^{-9}
1168.4	.0019	.095	4.2×10^{-9}
1216.2	.00195	.097	7.5×10^{-9}
1264.3	.0019	.095	7.0×10^{-9}
1336.7	.00205	.102	7.5×10^{-9}
1389.5	.00245	.122	--
1433.4	.0025	.127	1.3×10^{-8}
1552.3	.00265	.132	1.2×10^{-8}
1600.2	.0026	.130	2.6×10^{-9}
1672.4	.00265	.132	5.5×10^{-9}
1720.4	.0027	.135	3.8×10^{-9}
1768.5	.0028	.140	4.6×10^{-9}
1840.1	.0030	.150	4.4×10^{-9}
1936.3	.00310	.155	3.8×10^{-9}
1985.6	.00305	.152	3.8×10^{-9}
2035.2	.0032	.160	4.0×10^{-9}
2104.1	.0033	.165	3.8×10^{-9}
2176.1	.0034	.170	3.5×10^{-9}
2248.4	.00365	.182	4.2×10^{-9}
2272.2	.00355	.177	7.5×10^{-9}
2344.2	.0037	.185	2.4×10^{-9}
2396.9	.00375	.187	4.6×10^{-9}
2440.2	.00385	.187	4.4×10^{-9}
2512.0	.00395	.197	2.7×10^{-9}
2584.4	.00395	.197	2.9×10^{-9}
2680.2	.00395	.192	7.4×10^{-9}
2752.2	.0040	.200	5.4×10^{-9}

Test in Progress

TABLE A-IV

CREEP TEST DATA, TZC PLATE, RECRYSTALLIZED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2200°F (1204°C), 18,000 PSI (1.24×10^8 N/m^2)

Time (Minutes)	Length Change Δ L (in) (2" G.L.)	Creep (%)	Pressure (Torr)	Time (Hours)	Length Change Δ L (in) (2" G.L.)	Creep (%)	Pressure (Torr)
1	-.00005	-.0025	3×10^{-9}	64.3	.00110	.055	4.1×10^{-9}
2	-0-	-0-		88.4	.00120	.060	3.2×10^{-9}
3	-0-	-0-		112.5	.00140	.070	2.7×10^{-9}
4	-0-	-0-		136.4	.00165	.082	3.4×10^{-9}
5	-0-	-0-		160.4	.00215	.107	2.0×10^{-9}
10	.00005	.0025		232.5	.00255	.127	2.7×10^{-9}
20	.00010	.005		256.9	.00270	.135	1.8×10^{-9}
30	.00005	.0025		280.4	.00280	.140	1.8×10^{-9}
40	.00010	.005		304.3	.00310	.155	9.6×10^{-10}
60	.00005	.0025		328.5	.00325	.162	2.0×10^{-9}
				400.4	.00365	.182	1.7×10^{-9}
				427.1	.00390	.195	5.5×10^{-10}
				448.2	.00510	.255	1.8×10^{-9}
				472.3	.00580	.290	1.6×10^{-9}
				496.3	.00610	.305	1.4×10^{-9}
				568.4	.00660	.330	1.6×10^{-9}
				592.7	.00670	.335	1.2×10^{-9}
				616.7	.00670	.335	1.6×10^{-9}
				640.4	.00685	.342	1.4×10^{-9}
				664.4	.00715	.357	1.4×10^{-9}
				736.4	.00760	.380	1.7×10^{-9}
				760.4	.00740	.345	6.6×10^{-10}
				784.5	.00795	.397	1.4×10^{-9}
				808.3	.0080	.400	1.3×10^{-9}
				832.6	.0081	.405	---
				904.6	.0087	.435	1.2×10^{-9}
				929.4	.00875	.437	1.8×10^{-9}
				952.3	.00885	.442	1.4×10^{-9}
				976.5	.00895	.447	1.3×10^{-9}
				1072.3	.00980	.490	1.1×10^{-9}
				1096.5	.0100	.500	1.1×10^{-9}
				1120.4	.0101	.505	1.0×10^{-9}
				1147.6	.0102	.516	1.1×10^{-9}
				1168.5	.0103	.515	---
				1239.6	.0106	.530	1.5×10^{-9}
				1263.4	.0109	.545	1.0×10^{-9}
				1287.4	.01105	.552	9.5×10^{-10}
				1311.3	.01130	.565	1.0×10^{-9}
				1335.5	.01140	.570	1.2×10^{-9}

TABLE A-IV (Cont.)

CREEP TEST DATA, TZC PLATE, RECRYSTALLIZED AT 3092°F (1700°C) FOR 1 HOUR, TESTED AT 2200°F (1204°C), 18,000 PSI ($1.24 \times 10^8 N/m^2$)

Time (Hours)	Length Change ΔL(in.) 2" G.L.	Creep (%)	Pressure (Torr)
1407.9	.01155	.577	-
1431.4	.01190	.595	-
1460.7	.01250	.625	-
1479.4	.01285	.642	7.7×10^{-10}
1504.6	.01295	.647	8.2×10^{-10}
1575.4	.01305	.652	7.8×10^{-10}
1599.9	.01320	.660	8.0×10^{-10}
1623.5	.01385	.692	1.6×10^{-9}
1647.4	.01395	.697	8.7×10^{-10}
1671.4	.01410	.705	1.1×10^{-9}
1743.7	.01470	.735	9.7×10^{-10}
1767.4	.01720	.860	1.8×10^{-9}
1791.5	.01755	.877	1.2×10^{-9}
1815.6	.01795	.897	8.5×10^{-10}
1839.7	.01805	.902	8.0×10^{-10}
1911.3	.01855	.927	1.0×10^{-9}
1965.8	.01915	.957	1.2×10^{-9}
1984.1	.01935	.967	1.3×10^{-9}
2007.5	.01960	.980	1.1×10^{-9}
2056.9	.02005	1.000	1.0×10^{-9}
2103.4	.02100	1.050	9.4×10^{-10}
2128.2	.02120	1.060	1.3×10^{-10}

Test Terminated

TABLE A-V

Creep Test Data, TZC Plate, Recrystallized at 3092°F(1700°C) for 1 Hour, Tested at 2200°F (1204°C), 17,000 psi (1.17 X 10^8 N/m^2)

Time (Minutes)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
1	-0-	-0-	5.7 X 10^{-9}
2	-.00020	-.010	
3	-.00030	-.015	
4	-.00020	-.010	
5	-.00020	-.010	
6	-.00015	-.007	
7	-.00015	-.007	
8	-.00015	-.007	
9	-.00005	-.002	
10	-.00015	-.007	
15	-.00015	-.007	
20	-00015	-.007	
60	-00015	-.007	

TABLE A-V

Creep Test Data, TZC Plate, Recrystallized at 3092°F (1700°C) for 1 Hour, Tested at 2200°F (1204°C), 17,000 psi (1.17 X 10^8 N/m^2)

Time (Hours)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
85.6	.00165	.082	2.8×10^{-9}
108.9	.00160	.080	2.4×10^{-9}
133.1	.00180	.090	2.1×10^{-9}
229.1	.00245	.122	1.6×10^{-9}
254.0	.00240	.120	2.2×10^{-9}
277.0	.00260	.130	3.2×10^{-9}
301.5	.00265	.132	1.4×10^{-9}
325.2	.00265	.132	--
383.5	.00300	.150	1.5×10^{-9}
407.3	.00325	.162	2.6×10^{-9}
431.4	.00325	.162	2.4×10^{-9}
455.2	.00300	.150	1.2×10^{-9}
479.6	.00315	.157	3.2×10^{-9}
551.8	.00310	.155	1.4×10^{-9}
575.5	.00320	.160	1.2×10^{-9}
604.6	.00350	.175	--
623.4	.00370	.185	1.7×10^{-9}
648.5	.00380	.190	1.6×10^{-9}
719.2	.00390	.195	5.0×10^{-10}
743.7	.00390	.195	1.6×10^{-9}
767.6	.00395	.197	2.6×10^{-9}
791.2	.00410	.205	8.8×10^{-10}
815.2	.00410	.205	8.8×10^{-10}
887.2	.00430	.215	9.2×10^{-10}
911.2	.00465	.232	2.3×10^{-10}
935.5	.00475	.237	9.2×10^{-10}
959.4	.00475	.237	8.2×10^{-10}
983.5	.00480	.240	2.8×10^{-9}
1055.2	.00530	.265	1.0×10^{-9}
1109.8	.00550	.275	9.6×10^{-10}
1128.1	.00550	.275	9.3×10^{-10}
1151.5	.00565	.282	8.9×10^{-10}
1200.6	.00580	.290	1.4×10^{-9}
1247.2	.00590	.295	1.1×10^{-9}
1272.1	.00600	.300	8.8×10^{-10}
1295.3	.00615	.307	1.3×10^{-9}
1319.2	.00620	.310	7.9×10^{-10}
1391.2	.00690	.345	9.2×10^{-10}
1439.3	.00695	.347	4.6×10^{-10}
1487.3	.00690	.345	7.2×10^{-10}
1559.2	.00690	.345	4.9×10^{-9}
1612.0	.00705	.352	5.9×10^{-10}
1655.2	.00730	.365	5.0×10^{-10}
1727.1	.00785	.392	7.4×10^{-10}
1799.6	.00800	.400	5.6×10^{-10}
1895.5	.00820	.410	4.1×10^{-10}
1967.2	.00850	.425	4.5×10^{-10}

TABLE A-VI

CREEP TEST DATE, STRESS-RELIEVED TZM FORGED DISC, TESTED AT 2000°F (1093°C), 10,000 PSI ($6.89 \times 10^7 N/m^2$)

Time (Minutes)	Length Change L (in) (2" G. L.)	Creep (%)	Pressure (Torr)
1	-.00030	-.015	1.6×10^{-7}
2	-.00015	-.0075	
3	-.00015	-.0075	
4	-.00015	-.0075	
5	-.00005	-.0025	
6	.00010	.005	
7	.00005	.0025	
8	.0000	.000	
9	.00010	.005	
10	.00005	.0025	
15	.00005	.0025	
20	.00010	.005	
25	.00005	.0025	
30	.00000	.0000	
45	.00010	.005	
60	.00015	.0075	
75	.00005	.0025	
90	.00010	.005	
(Hours)			
20.0	-.00005	-.0025	6.7×10^{-8}
74.7	.00030	.015	1.0×10^{-8}
125.7	.00100	.05	1.4×10^{-8}
136.5	.00080	.04	1.0×10^{-8}
160.3	.00085	.0425	5.7×10^{-9}
184.4	.00085	.0425	4.4×10^{-9}
208.5	.00090	.045	4.0×10^{-9}
232.2	.00090	.045	3.4×10^{-9}
304.4	.00100	.05	2.2×10^{-9}
328.3	.00100	.05	2.0×10^{-9}
1360.3	.00250	.125	5.8×10^{-10}
1384.3	.00250	.125	5.2×10^{-10}
1408.5	.00250	.125	4.4×10^{-10}
1480.3	.00260	.13	4.6×10^{-10}
1552.2	.00270	.135	4.6×10^{-10}
1648.3	.00320	.16	4.0×10^{-10}
1696.4	.00320	.16	3.8×10^{-10}
1720.6	.00320	.16	4.4×10^{-10}
1816.4	.00320	.16	5.7×10^{-10}
1864.2	.00315	.157	3.8×10^{-10}
1912.3	.00325	.162	4.0×10^{-10}

Time (Hrs.)	Length Change Δ L (in) (2" G.L.)	Creep (%)	Pressure (Torr)
352.3	.00105	.0525	1.9×10^{-9}
376.6	.00105	.0525	1.3×10^{-9}
400.8	.00110	.055	2.1×10^{-9}
457.5	.00130	.065	1.3×10^{-9}
472.6	.00135	.0675	1.2×10^{-9}
497.0	.00140	.070	1.2×10^{-9}
520.2	.00145	.0725	1.2×10^{-9}
544.1	.00145	.0725	1.2×10^{-9}
568.2	.00150	.075	1.2×10^{-9}
640.2	.00155	.0775	1.5×10^{-9}
664.3	.00170	.085	9.2×10^{-10}
712.3	.00175	.0875	7.4×10^{-10}
736.3	.00170	.085	7.6×10^{-10}
810.2	.00175	.0875	1.3×10^{-9}
832.2	.00185	.0925	9.0×10^{-10}
856.1	.0018	.090	9.2×10^{-10}
880.1	.0020	.100	7.5×10^{-10}
904.0	.00205	.1025	7.7×10^{-10}
982.8	.00210	.105	8.1×10^{-10}
1000.2	.00210	.105	7.6×10^{-10}
1024.2	.00210	.105	8.2×10^{-10}
1048.3	.00220	.110	8.0×10^{-10}
1072.1	.00220	.110	1.3×10^{-9}
1144.0	.00230	.115	6.9×10^{-10}
1168.3	.00235	.1175	6.9×10^{-10}
1192.2	.00240	.120	6.6×10^{-10}
1216.4	.00250	.125	6.4×10^{-10}
1240.2	.00250	.125	5.8×10^{-10}
1336.2	.00250	.125	5.9×10^{-10}

TABLE VI - Cont'd

Time (Hours)	Length Change, Δ L (in) (2" G.L.)	Creep (%)	Pressure (Torr)
1984.3	.00330	.165	2.6×10^{-10}
2032.2	.00335	.167	3.6×10^{-10}
2080.1	.00340	.170	3.1×10^{-10}
2152.3	.00340	.170	2.8×10^{-10}
2200.6	.00325	.167	2.3×10^{-10}
2248.4	.00340	.170	1.6×10^{-10}
2320.4	.00350	.175	2.7×10^{-10}
2369.4	.00345	.172	2.0×10^{-10}
2418.3	.00355	.177	9.2×10^{-11}
2488.4	.00345	.172	4.0×10^{-10}
2536.1	.00350	.175	1.7×10^{-10}
2560.3	.00345	.172	2.6×10^{-10}
2656.3	.00355	.177	2.6×10^{-10}
2704.3	.00350	.175	---
2752.4	.00350	.177	---
2823.5	.00355	.177	2.5×10^{-10}
2871.3	.00365	.182	1.1×10^{-11}
2919.5	.00375	.187	1.7×10^{-10}
2991.7	.00380	.190	7.2×10^{-11}
3044.5	.00380	.190	---
3088.4	.00380	.190	1.8×10^{-11}
3159.2	.00385	.192	1.6×10^{-11}
3231.2	.00390	.195	1.4×10^{-10}
3327.5	.00385	.192	1.2×10^{-10}
3399.4	.00395	.197	2.0×10^{-11}
3495.1	.00400	.200	8.2×10^{-12}
3568.1	.00400	.200	9.5×10^{-11}
3640.6	.00410	.205	3.4×10^{-11}
3687.6	.00410	.205	1.9×10^{-11}
3735.3	.00415	.207	1.0×10^{-11}
3831.1	.00420	.210	1.2×10^{-11}
3903.5	.00425	.212	2.1×10^{-11}
3999.2	.00440	.220	1.0×10^{-11}
4071.3	.00450	.225	2.1×10^{-11}

TABLE A-VII

CREEP TEST DATA, TZM FORGED DISC, ANNEALED AT 2850°F (1566°C), FOR 1 HOUR, TESTED AT 2000°F (1093°C) 10,000 PSI (6.89×10^7 N/m^2)

Time (Minutes)	Length Change ΔL (in.) 2" G. L.	Creep %	Pressure Torr
1	.00030	.015	6.0×10^{-10}
2	.00045	.0225	
3	.00040	.020	
4	.00030	.015	
5	.00025	.0125	
6	.00015	.0075	
7	.00015	.0075	
8	.00010	.005	
9	.00020	.010	
10	.00030	.015	
11	.00030	.015	
12	.00025	.0125	
13	.00030	.015	
14	.00030	.015	
15	.00035	.0175	
20	.00045	.0225	
25	.00050	.025	
30	.00055	.0275	
35	.00050	.025	
40	.00050	.025	
45	.00050	.025	
60	.00050	.025	

Time (Hours)	Length Change L (in.) 2" G. L.	Creep %	Pressure Torr
16.6	.00040	.020	6.2×10^{-9}
40.7	.00055	.0275	3.1×10^{-9}
114.5	.00095	.0475	5.1×10^{-9}
136.5	.00105	.0525	3.0×10^{-9}
160.4	.00120	.060	3.4×10^{-9}
184.4	.00130	.065	2.4×10^{-9}
208.3	.00140	.070	2.3×10^{-9}
287.5	.00180	.090	2.2×10^{-9}
304.7	.00235	.1175	1.8×10^{-9}
328.7	.00505	.2525	1.6×10^{-9}
336.5	.00485	.2425	
352.6	.00515	.2575	1.6×10^{-9}
374.4	.00525	.2625	2.2×10^{-9}
448.3	.00525	.2625	1.4×10^{-9}
472.7	.00525	.2625	1.0×10^{-9}
496.6	.00530	.265	1.0×10^{-9}
520.8	.00535	.2675	1.6×10^{-9}
544.6	.00565	.2825	1.2×10^{-10}
616.6	.00560	.280	6.2×10^{-10}
640.5	.00555	.2775	7.2×10^{-10}
664.6	.00560	.280	7.2×10^{-10}
688.7	.00560	.280	7.3×10^{-9}
712.8	.00565	.2825	1.3×10^{-10}
784.6	.00560	.280	5.6×10^{-10}
808.7	.00555	.277	5.5×10^{-10}
832.6	.00565	.282	5.8×10^{-10}
856.6	.00575	.287	5.8×10^{-10}
880.6	.00580	.290	6.6×10^{-10}
952.6	.00480	.240	4.3×10^{-9}
977.0	.00485	.242	1.4×10^{-10}
1000.7	.00485	.242	4.2×10^{-10}
1025.0	.00505	.252	7.2×10^{-10}
1049.3	.00440	.220	4.6×10^{-10}
1120.8	.00465	.232	3.2×10^{-10}
1145.2	.00485	.242	4.3×10^{-10}
1168.5	.00505	.252	5.0×10^{-10}
1192.7	.00515	.257	8.0×10^{-10}
1216.6	.00515	.257	3.0×10^{-10}
1288.6	.00510	.255	1.6×10^{-10}
1315.5	.00525	.262	2.2×10^{-10}
1336.5	.00525	.262	1.5×10^{-10}
1360.7	.00520	.260	1.6×10^{-10}
1384.5	.00525	.262	2.1×10^{-10}

TABLE A-VII (Continued)

Time (Hours)	Length Change ΔL (in.) 2" G.L.	Creep %	Pressure Torr
1456.6	.00540	.270	4.4×10^{-10}
1480.9	.00520	.260	1.6×10^{-9}
1505.0	.00505	.252	9.7×10^{-11}
1528.5	.00510	.255	1.3×10^{-9}
1552.8	.00520	.260	1.3×10^{-9}
1649.0	.00530	.265	9.3×10^{-10}
1696.6	.00535	.267	--
1722.7	.00530	.265	--
1792.8	.00530	.265	3.2×10^{-12}
1840.7	.00530	.265	8.8×10^{-11}
1840.7	.00530	.265	8.8×10^{-11}
1960.8	.00540	.270	9.6×10^{-10}
1984.8	.00545	.272	3.6×10^{-10}
2008.6	.00545	.272	1.5×10^{-9}
2056.9	.00550	.275	--
2115.2	.00555	.277	3.2×10^{-10}
2163.0	.00550	.275	8.0×10^{-10}
2211.2	.00545	.272	1.4×10^{-9}
2283.4	.00560	.280	1.1×10^{-9}
2336.3	.00560	.280	--
2380.1	.00550	.275	1.4×10^{-11}
2450.9	.00555	.277	1.4×10^{-11}
2523.0	.00570	.285	1.0×10^{-9}
2619.2	.00570	.285	8.6×10^{-10}
2691.0	.00610	.305	--
2786.8	.00635	.317	2.5×10^{-10}
2859.8	.00640	.320	8.8×10^{-11}
2932.3	.00640	.320	1.4×10^{-10}
2978.9	.00640	.320	2.2×10^{-10}
3027.0	.00580	.290	1.2×10^{-10}
3122.9	.00630	.315	2.6×10^{-10}
3195.2	.00605	.302	2.8×10^{-10}
3363.0	.00650	.325	1.2×10^{-9}
3458.8	.00645	.322	2.4×10^{-10}
3531.2	.00655	.327	9.2×10^{-10}
3627.1	.00640	.320	2.4×10^{-11}
3699.0	.00655	.327	4.2×10^{-10}

Table A-VIII

Creep Test Data for TZM Material Received from NASA Tested at 1800°F (982°C), 24,000psi ($1.65 \times 10^8 N/m^2$)

Time (Hours)	Length Change Δ L (in.) 2" G. L.	Creep (%)	Pressure (Torr)
66.9	.00010	-	3.7×10^{-8}
88.5	.00005	-	3.7×10^{-8}
117.1	.00005	-	2.3×10^{-8}
136.4	0.00000	-	1.6×10^{-8}
160.4	.00005	-	1.6×10^{-8}
232.2	.00020	.010	9.8×10^{-9}
256.7	.00015	.007	8.8×10^{-9}
280.6	.00020	.010	5.6×10^{-9}
304.5	.00020	.010	6.7×10^{-9}
329.8	.00030	.015	6.1×10^{-9}
400.4	.00025	.012	4.2×10^{-9}
424.4	.00030	.015	3.7×10^{-9}
448.7	.00035	.017	3.4×10^{-9}
472.4	.00040	.020	2.6×10^{-9}
496.5	.00040	.020	-

TABLE A-VIII

Creep Test Data for TZM Material Received from NASA Tested at 1856°F (1013°C), 24,000 psi ($1.65 \times 10^8 N/m^2$)

Time (Minutes)	Length Change ΔL (in.) 2" G. L.	Creep %	Pressure Torr
1	-.00010	-.005	3.2×10^{-7}
2	-.00015	-.007	
3	-.00010	-.005	
4	-.00005	-.002	
5	-.00010	-.005	
6	-.00010	-.005	
7	-.00010	-.005	
8	-.00005	-.002	
9	-.00010	-.005	
10	-.00005	-.002	
15	-.00020	-.010	
30	-.00020	-.010	
60	-.00015	-.007	

TABLE A-IX

CREEP TEST DATA FOR Cb132M, ANNEALED 3092°F (1700°C) FOR ONE HOUR

TESTED AT

2056°F (1124°C), 20,000 PSI (1.38×10^8 N/m^2)

Time (Minutes)	Length Change, ΔL (in.) 2" G.L.	Creep (%)	Pressure Torr
1	-		
2	-0-	-0-	
3	.00005	.002	
4	-0-	-0-	
5	-0-	-0-	
6	-0-	-0-	
7	.00030	.005	
8	.00030	.015	
9	.00020	.010	
10	.00025	.012	
15	.00030	.015	
20	.00030	.015	8.2×10^{-10}
25	.00030	.015	
30	.00030	.015	
Time (Hours)			
64.6	.00210	.105	1.1×10^{-9}
88.4	.00285	.142	7.8×10^{-10}
117.4	.00410	.205	---
136.3	.00435	.217	8.2×10^{-10}
161.3	.00525	.262	8.8×10^{-10}
232.1	.00835	.417	5.2×10^{-10}
256.5	.00910	.455	4.2×10^{-10}
280.6	.01020	.510	4.4×10^{-10}
304.1	.01085	.542	5.5×10^{-10}
328.1	.01145	.572	4.6×10^{-10}
400.4	.01585	.792	1.8×10^{-10}
424.1	.01615	.807	3.3×10^{-10}
448.3	.01780	.890	3.3×10^{-10}
472.2	.01935	.967	4.6×10^{-10}
496.4	.02000	1.00	4.1×10^{-10}
568.0	.02340	1.17	---

TEST TERMINATED

TABLE A-X

CREEP TEST DATA FOR Cb132M, ANNEALED 3092°F (1700°C) FOR 1 HOUR

TESTED AT 2056°F (1124°C), 17,000 PSI ($1.17 \times 10^8 N/m^2$)

Time (Minutes)	Length Change ΔL (in.) 2" G. L.	Creep %	Pressure Torr
1	.00005	.002	8.5×10^{-10}
2	.00010	.005	
3	.00005	.002	
4	-0-	-0-	
5	.00005	.002	
6	.00010	.005	
7	.00010	.005	
8	.00015	.007	
9	.00015	.007	
10	.00015	.007	
15	.00035	.017	
20	.00055	.027	
25	.00050	.025	
30	.00050	.025	
60	.00055	.027	

Table A-X (Cont'd.)

Creep Test Data for Cb132M, Annealed 3092°F (1700°C) For 1 Hour
Tested at 2056°F (1124°C), 17,000 psi ($1.17 \times 10^8 N/m^2$)

Time (Hours)	Length Change ΔL (in.) (2" G.L.)	Creep (%)	Pressure (Torr)
19.0	.00115	.057	9.2×10^{-10}
42.9	.00255	.127	8.1×10^{-10}
114.9	.00415	.207	9.3×10^{-10}
139.1	.00525	.262	9.3×10^{-10}
163.0	.00580	.290	4.1×10^{-10}
187.2	.00650	.325	7.2×10^{-10}
211.0	.00665	.332	3.8×10^{-10}
283.0	.00865	.432	4.7×10^{-10}
307.1	.00935	.467	3.6×10^{-10}
335.6	.00975	.437	4.3×10^{-10}
355.0	.01055	.527	4.0×10^{-10}
378.9	.01095	.547	3.8×10^{-10}
450.8	.01335	.667	3.4×10^{-10}
475.3	.01375	.687	5.3×10^{-10}
499.1	.01405	.702	2.1×10^{-10}
523.2	.01525	.763	4.6×10^{-10}
549.2	.01595	.797	5.2×10^{-10}
619.2	.01765	.883	4.7×10^{-10}
643.0	.01910	.955	3.3×10^{-10}
667.2	.01995	.997	3.8×10^{-10}
691.0	.02055	1.020	3.9×10^{-10}

Test Terminated

TABLE A-XI

CREEP TEST DATA, W-25%Re SHEET, TESTED AT 3200°F (1760°C), 1500 PSI ($1.03 \times 10^7 N/m^2$)

Time (Minutes)	Length Change Δ L (in.) 2" G. L.	Creep %	Pressure Torr
5	.00005	.002	
10	.00010	.005	
15	.00010	.005	
20	.00010	.005	
30	.00010	.005	
45	.00010	.005	
60	.00010	.005	

TABLE A-XI (Cont'd.)

CREEP TEST DATA, W-25%Re SHEET, TESTED AT 3200°F (1760°C), 1500 PSI (1.03 x 10^7N/m^2)

Time (Hours)	Length Change ΔL (inch) (2" G. L.)	Creep (%)	Pressure (Torr)
10.6	.00005	0.0025	1.4×10^{-7}
82.7	.00450	0.2250	2.1×10^{-8}
106.6	.00700	0.3500	2.0×10^{-8}
130.6	.00735	0.3675	1.6×10^{-8}
154.6	.01065	0.5325	1.6×10^{-8}
178.8	.01170	0.5850	1.4×10^{-8}
250.6	.01535	0.7670	1.0×10^{-8}
274.5	.01730	0.8650	9.8×10^{-9}
298.6	.01795	0.8970	1.0×10^{-8}
322.5	.02135	1.0670	9.6×10^{-9}
346.7	.02195	1.0970	9.4×10^{-9}
418.5	.02480	1.2400	8.5×10^{-9}
422.9	.02700	1.3500	1.5×10^{-8}
466.7	.02910	1.4550	8.4×10^{-9}
490.7	.03225	1.6120	1.0×10^{-8}
515.0	.03345	1.6720	9.6×10^{-9}
586.0	.03870	1.9350	1.0×10^{-8}
611.1	.04010	2.0050	9.2×10^{-9}
634.6	.04140	2.0700	8.9×10^{-9}
658.7	.04300	2.1500	1.2×10^{-8}
682.7	.04490	2.2450	7.9×10^{-9}
754.7	.05065	2.5320	7.0×10^{-9}
781.3	.05385	2.6920	7.5×10^{-9}
802.6	.05525	2.7620	7.2×10^{-9}
826.6	.05700	2.8500	7.2×10^{-9}
850.5	.05835	2.9170	8.3×10^{-9}
922.6	.06480	3.2400	8.8×10^{-9}
946.9	.06820	3.4100	1.4×10^{-8}
970.9	.06940	3.4700	4.4×10^{-9}
994.6	.07210	3.6050	4.8×10^{-9}
1018.6	.07370	3.6850	5.0×10^{-9}
1090.6	.08120	4.0600	5.9×10^{-9}
1114.8	.08305	4.1520	9.0×10^{-9}
1139.8	.08525	4.2520	5.8×10^{-9}
1162.5	.08795	4.3970	6.4×10^{-9}
1188.3	.09065	4.5320	----
1258.9	.09770	4.8850	4.2×10^{-9}
1283.3	.10085	5.0420	----

Test Terminated

TABLE A-XII

CREEP TEST DATA, TUNGSTEN SHEET, TESTED AT 3200°F (1760°C)

Time (Minutes)	Length Change ΔL (in.) 2" G. L.	Creep %	Pressure Torr
1	.00005	.002	4×10^{-8}
2	.00015	.007	
3	.00015	.007	
4	.00010	.005	
5	.00015	.007	
6	.00020	.010	
7	.00020	.010	
8	.00020	.010	
9	.00020	.010	
10	.00015	.007	
15	.00020	.010	
20	.00010	.005	
25	.00020	.010	
30	.00020	.010	
60	.00020	.010	
90	.00030	.015	

TABLE A-XII (Cont'd.)

CREEP TEST DATA, TUNGSTEN SHEET, TESTED AT 3200°F (1760°C), 1000 PSI ($6.89 \times 10^6 N/m^2$)

Time (Hours)	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
16.6	.00180	0.090	2.2×10^{-8}
88.4	.00480	0.240	1.0×10^{-8}
112.4	.00615	0.307	1.1×10^{-8}
136.3	.00750	0.375	9.2×10^{-9}
160.3	.00880	0.440	7.8×10^{-9}
184.4	.00960	0.480	6.9×10^{-9}
256.3	.01115	0.557	5.6×10^{-8}
280.7	.01190	0.595	1.6×10^{-8}
304.5	.01215	0.607	3.9×10^{-9}
328.4	.01265	0.632	6.8×10^{-9}
352.7	.01330	0.665	6.5×10^{-9}
424.5	.01575	0.787	7.2×10^{-9}
448.9	.01725	0.862	6.1×10^{-9}
472.3	.01705	0.852	6.3×10^{-9}
496.4	.01725	0.862	9.0×10^{-9}
520.4	.01740	0.870	4.6×10^{-8}
592.4	.01810	0.905	5.0×10^{-8}
619.1	.01930	0.965	3.6×10^{-8}
640.3	.01960	0.980	4.9×10^{-8}
664.3	.02010	1.005	4.7×10^{-8}
688.2	.02040	1.020	4.0×10^{-8}
760.4	.02155	1.072	4.6×10^{-9}
784.6	.02190	1.095	1.5×10^{-8}
808.7	.02305	1.152	7.2×10^{-9}
823.3	.02375	1.187	2.4×10^{-9}
856.3	.02455	1.222	2.4×10^{-9}
928.5	.02465	1.232	3.0×10^{-9}
952.5	.02570	1.285	2.3×10^{-9}
977.5	.02660	1.330	8.2×10^{-9}
1000.3	.02715	1.357	2.4×10^{-9}
1026.3	.02775	1.387	----
1096.6	.02850	1.425	8.3×10^{-9}
1121.1	.02875	1.437	8.0×10^{-9}
1143.3	.02930	1.465	----
1168.4	.03040	1.520	9.4×10^{-9}
1264.3	.03120	1.560	9.2×10^{-9}
1288.4	.03145	1.572	2.8×10^{-9}

TABLE A-XII (Continued)

Time (Hours)	Length Change ΔL (inch) (2" G.L.)	Creep (%)	Pressure (Torr)
1312.4	.03210	1.655	6.7×10^{-9}
1336.9	.03265	1.632	2.4×10^{-9}
1360.5	.03300	1.650	----
1431.6	.03345	1.672	4.6×10^{-10}
1455.4	.03430	1.715	2.4×10^{-9}
1479.4	.03445	1.723	3.2×10^{-9}
1503.2	.03455	1.727	6.8×10^{-9}
1527.5	.03460	1.730	6.6×10^{-9}
1599.8	.03525	1.762	5.3×10^{-9}
1623.3	.03550	1.775	3.0×10^{-9}
1652.7	.03630	1.815	----
1671.4	.03665	1.832	1.8×10^{-9}
1691.6	.03690	1.845	2.0×10^{-9}
1767.3	.03745	1.872	1.8×10^{-9}
1791.8	.03810	1.905	1.7×10^{-9}
1815.4	.03825	1.912	1.7×10^{-9}
1839.3	.03850	1.925	6.0×10^{-9}
1863.3	.03865	1.932	3.2×10^{-10}
1935.6	.03910	1.955	6.2×10^{-9}
1983.5	.04010	2.005	2.5×10^{-9}
2031.7	.04040	2.020	7.3×10^{-9}
2103.2	.04100	2.050	2.2×10^{-9}
2157.7	.04135	2.067	7.4×10^{-9}
2199.5	.04180	2.090	----
2248.8	.04205	2.102	----
2295.3	.04260	2.130	2.3×10^{-9}
2320.2	.04275	2.137	2.8×10^{-9}
2367.3	.04325	2.162	2.1×10^{-9}
2439.2	.04370	2.185	2.2×10^{-9}
2487.4	.04420	2.210	2.0×10^{-9}
2535.3	.04465	2.232	6.6×10^{-9}
2607.3	.04555	2.277	1.4×10^{-9}
2660.1	.04620	2.310	7.0×10^{-9}
2703.3	.04570	2.285	5.6×10^{-9}
2775.2	.04710	2.352	1.7×10^{-9}
2847.5	.04770	2.385	1.6×10^{-9}
2943.6	.04850	2.425	2.0×10^{-9}
3015.4	.04940	2.470	5.0×10^{-9}

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